LUT Wrap Up

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LONG-TERM GOAL

The overall goal of this work is to develop and validate a spectrum-matching and look-up-table (LUT) technique for rapidly and accurately inverting remotely sensed hyperspectral reflectances to extract environmental information such as bathymetry, and bottom classification, and water-column optical properties.

OBJECTIVES

My colleague W. P. Bissett and I have developed (Mobley et al., 2005) and evaluated (Mobley and Lesser, 2007; Dekker et al., 2011) new techniques for the extraction of environmental information including shallow-water bathymetry, bottom classification, and water-column inherent optical properties (IOPs), from remotely-sensed hyperspectral ocean-color imagery. We have addressed the need for rapid, semi-automated interpretation of such imagery. My research centered on development and evaluation of the spectrum-matching algorithms, including the generation of confidence metrics for the retrieved information.

My initial objectives during the current year were to "wrap up" the previous developments by (1) documenting the "lessons learned" about what works well and what does not; (2) clean up the computer codes; (3) create more extensive databases of remote-sensing reflectances R_{rs} so that the existing algorithms can be applied to a wider range of environments; (4) prepare a user's guide for the processes of creating new databases, processing images with the algorithms previous developed, and displaying the results; (5) transfer the code to NRL for beta testing. Additional on-going work centers on evaluating World View 2 satellite multi-spectral imagery for retrieval of bathymetry.

APPROACH

The methodology is based on a spectrum-matching and look-up-table approach in which the measured remote-sensing reflectance spectrum R_{rs} is compared with a database of spectra corresponding to known water, bottom, and external environmental conditions. The water and bottom conditions of the water body where the image spectrum was measured are then taken to be the same as the conditions corresponding to the database spectrum that most closely matches (by some chosen metric) the

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measured spectrum. In previous work, we have simultaneously retrieved water column IOPs, bottom depth, and bottom classification at each pixel from image remote-sensing reflectance spectra. Although this is much to ask from an R_{rs} spectrum, we have shown that all of this information is uniquely contained in hyperspectral reflectance signatures and that the information can be extracted with sufficient accuracy to meet many Naval and civilian needs.

We have evaluated numerous options for applying the basic algorithms. These options include matching the closest k R_{rs} spectra, rather than just the closest one ($k = 1$); spectral and spatial smoothing of image spectra before processing to remove both sensor and environmental noise (such as whitecaps and sun glint); spatial smoothing of retrieved values after processing; and different spectrum-matching metrics for determining the closest match.

WORK COMPLETED

Previously developed software for database creation, image analysis, and display of results was cleaned up, extensively documented, and repackaged into one software system that is now called Comprehensive Reflectance Inversion based on Spectrum matching and TAble Look up, or CRISTAL. A CRISTAL User's Guide and Technical Documentation was prepared (Mobley and Bissett, 2011).

The CRISTAL database generation software uses the extremely fast EcoLight-S radiative transfer code (Mobley 2010, 2011), which can be optimized to run much faster than the standard EcoLight code but with a negligible difference in the computed R_{rs}. The run time savings come primarily from not solving the radiative transfer equation to the same depth at all wavelengths, especially at wavelengths beyond 700 nm where the bottom has no influence on R_{rs} if the water is more than a few meters deep. EcoLight-S is described in my separate report on contract N0001409C0044.

I had previously written over 300 pages of formal notes summarizing the results of my investigations of various algorithms and techniques for improving the products retrieved from imagery, including techniques for estimation of retrieval errors. Those notes were condensed into a CRISTAL User's Guide and Technical Documentation, which also contains new material and example retrievals, as well as instructions on how to run the code. Parts of the User's Guide be condensed into a journal article on the lessons learned and progress made since the original Mobley et al. (2005) publication.

The most recent versions of the CRISTAL code and documentation were given to Dr. A. Weidemann, NRL Code 7334, for beta testing and evaluation. His comments will be used to create the final versions of the code and documentation.

Previous work considered only airborne hyperspectral imagery, mostly of optically clear waters (Mobley et al., 2005; Mobley and Lesser, 2007; Dekker et al., 2011). This year I began to evaluate the CRISTAL techniques for retrievals in highly absorbing and scattering (turbid) waters using the multispectral World View 2 satellite imagery. This work required the development of new code to reprocess hyperspectral R_{rs} databases to create databases corresponding to the multi-spectra bands of the World View 2 imagery.

RESULTS

Figure 1 shows a World View 2 false-color image of a spatially complex area at the south end of St. Joseph Bay, FL; the imaged area is about 2.5 km square with a nominal pixel size of about 2 m. This water is highly absorbing due to CDOM (absorption coefficients at 412 nm are in the range of 0.5 to 1.0 m^{-1}) and highly scattering due to suspended particles (scattering coefficients are in the 0.5 to 2.5 m^{-1} range). The bottom is predominately bare sand or dense sea grass. Depths range from the shoreline to several meters; these waters are optically deep if the bottom is below about 3 m depth.

To process the World View 2 image, a hyperspectral R_{rs} database was created by CRISTAL for 0.38-0.75 µm by 0.005 µm, which covers the World View 2 wavelengths relevant to bathymetry retrievals. That database was then integrated over the World View 2 band response functions to degrade the hyperspectral database to the multispectral bands of the World View 2 sensor. Figure 2 shows the World View 2 sensor response functions and selected hyperspectral reflectances and their World View 2 multispectral equivalents.

Figure 3 shows the CRISTAL-retrieved depths for the area of Fig. 1, as obtained from World View 2 imagery. Other than atmospheric correction via an empirical line fit based on measured R_{rs} spectra in this area, no adjustment of the World View 2 image spectra was done before processing. These depths appear to be fairly good in the optically shallow areas. However, the optically deep channel (blue in the figure) is often retrieved with the bottom being shallower. This appears to be due to a confusion of optically deep water with shallower water with a dark reflecting bottom.

We certainly cannot expect that any multispectral imagery can give results as accurate as can be obtained from good quality hyperspectral imagery. However, the very preliminary evaluation of World View 2 multispectral imagery shown here indicates that this satellite imagery may be useful for retrieval of high-spatial-resolution (~2 m pixel size) bathymetry with sufficient accuracy for many purposes. However, the evaluation of World View 2 imagery is still underway, and more images must be examined and compared with ground truth before reaching any firm conclusions about the quantitative accuracy of multispectral World View 2 imagery vs. hyperspectral airborne imagery.

IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of Naval needs as well as to basic science and ecosystem monitoring and management problems. Extraction of bathymetry and bottom classification is especially valuable for planning military operations in denied access areas. The initial evaluation of World View 2 multispectral imagery for high-spatial-resolution (~2 m) bathymetry retrieval is encouraging because this imagery is readily available to both military and civilian users. We believe that the CRISTAL methodology and software will find applications to a wide range of ocean image processing problems both within the Navy and in the broader science community.

TRANSITIONS

A beta-test version of the CRISTAL software package has been send to Dr. A. Weidemann, NRL Code 7334 for evaluation and comment.

Various databases of water IOPs, bottom reflectances, and the corresponding R_{rs} spectra, along with spectrum-matching algorithms and code have been transitioned to Dr. Paul Bissett at WeoGeo, Inc. for processing his extensive collection of SAMPSON imagery acquired in coastal California and Florida waters, and for use in comparisons of CRISTAL and LIDAR bathymetry. Code for display of retrieval results was given to S. Phinn and colleagues at the Univ. of Queensland, Australia, who performed comparisons of CRISTAL and other retrieval techniques.

RELATED PROJECTS

This work is being conducted in conjunction with Dr. Paul Bissett at WeoGeo, Inc, who was separately funded for his contributions to the development of CRISTAL, and who is currently funded via a subcontract for the evaluation of World View 2 imagery for bathymetry retrieval. The development of the EcoLight-S code, which is incorporated into the final CRISTAL database generation code, was supported in part by contract N0001409C0044.

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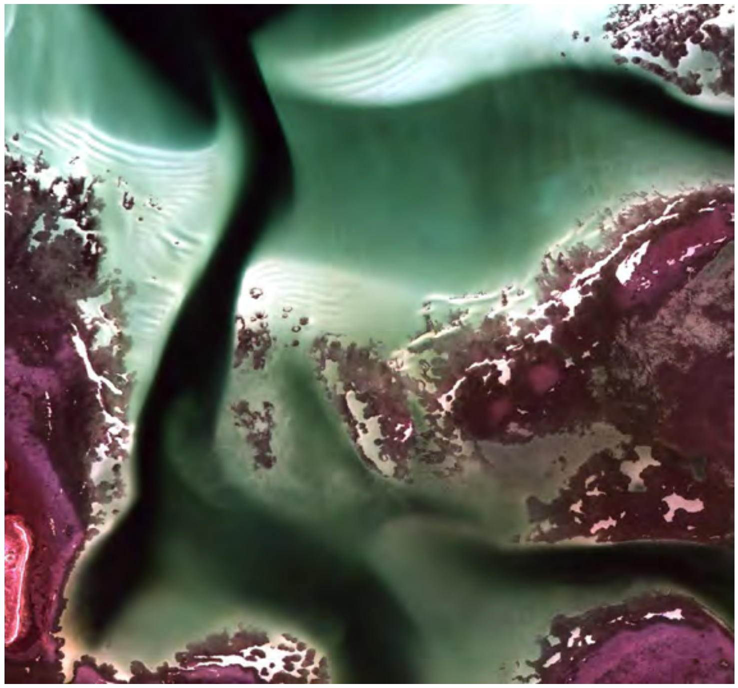

Fig. 1. False color image of a 2.5 km square area at the south end of St. Joseph Bay, Florida. The white to green areas are sand bottom down to ~3 m depth. The purple areas are dense sea grass beds down to ~1 m deep. The darkest channels are optically deep (> 3 m for these turbid waters).

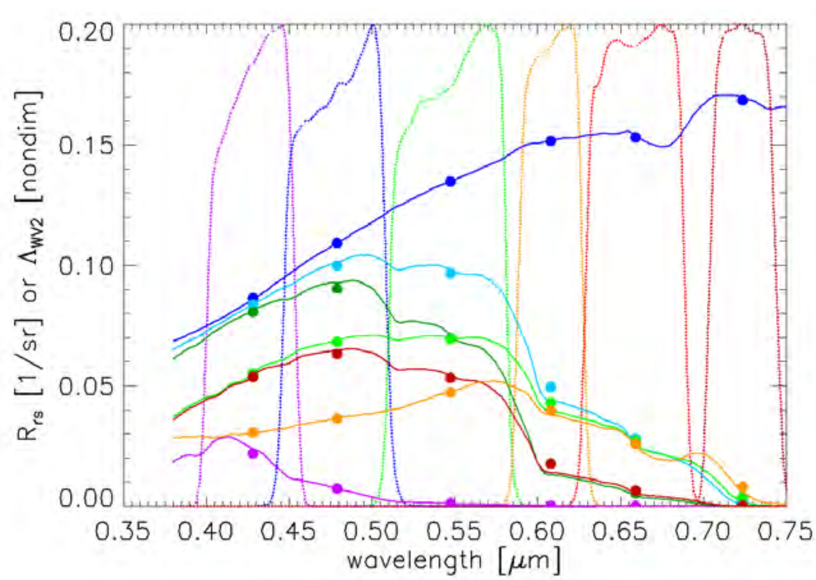

Fig 2. The dotted lines are World View 2 normalized sensor response functions $\Lambda_{WV2}(\lambda)$ for the six World View 2 bands used for spectrum matching. The solid lines are example hyperspectral reflectances $R_{rs}(\lambda)$, and the dots are the equivalent World View 2 multispectral band values.

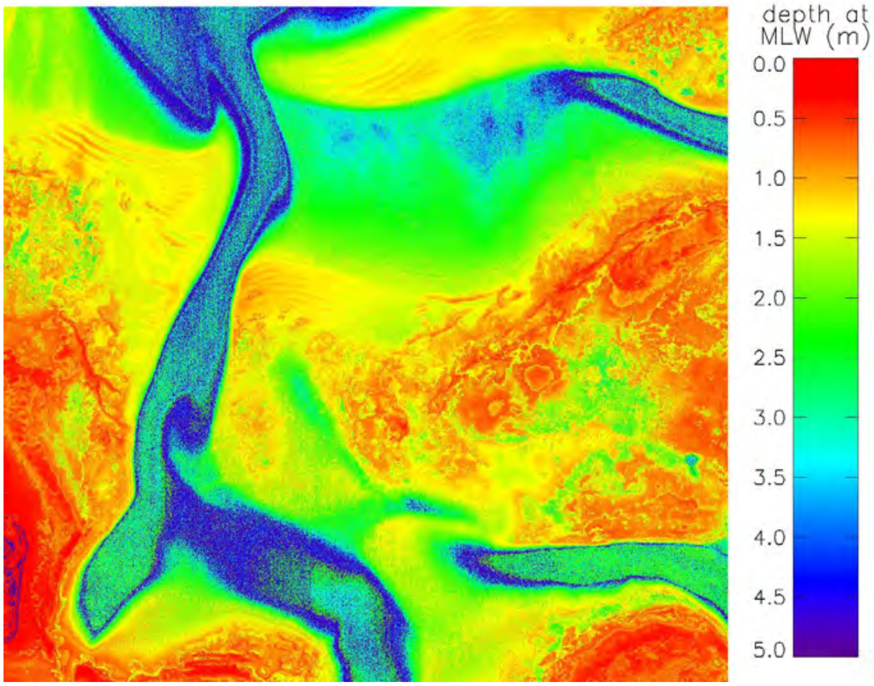

Fig. 3. CRISTAL-retrieved depths obtained from World View 2 multi-spectral imagery for the area shown in Fig. 1. Depths retrieved at the time of image acquisition were corrected for tidal height to get depths at mean low water.